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AN ARCHITECT IN A WORLD WHERE APPLES DO NOT FALL

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16. Abstract The author offers some thoughts on the problems facing architects in the design and construction of living quarters of future habitats in space without gravitation. He recognizes the fact that such constructions can be fully useful only if advances in biomedical sciences will determine the feasibility of (or find the means for) long-term survival in weightlessness. He urges full comprehension of the overwhelming influence of gravitation on the construction of our houses, features of furnishings, and the living space itself, which is reduced to horizontal surfaces. The architecture of weightlessness will not know the size and shape restrictions, and the living space itself will be truly tridimensionally functional. It is the problem of the architect to organize this space, and his main difficulty may be in the capacity of liberating himself from habitual "two-dimensional" thinking. The article is accompanied by favorable comments from cosmonaut Alexey Yeliseyev, Dr. of Tech. Sciences and Twice Hero of the USSR, and a prominent architect.

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AN ARCHITECT IN A WORLD WHERE APPLES DO NOT FALL

Yaroslav Golovanov

The history of the development of science in recent decades is full of numerous examples as to how achievements in one field of knowledge have opened new horizons in another field seemingly unrelated in any way to the first. /212*

The study of radioactivity, in particular, has had the result that archeologists and paleontologists have been able to make more accurate chronological determinations of their findings. Success in computer technology has permitted psychologists and linguists to conduct research of which they could not even dream previously. I repeat that there are very many examples, and I would like to add one more line to this long list. To be more precise, I do not wish to add, but merely to direct attention to the fact that this line may be added in the very nearest future.

It is quite probable that the solution of certain medical and physiological problems can radically change our conceptions of architectural potentials. Since I cannot consider myself a specialist either in the field of medicine or architecture, I ask that you examine all that I have written, only remaining within the framework of this question. I am arguing nothing and do not even invite an argument, since I am not ready for an argument myself, but merely suggest material for thought.

SERPENT AND CALIPERS

The launching of the first artificial Earth satellite in history was actually a purely engineering problem, although an exceptionally complex one. After all, the principle itself of rocket flight in space had been scientifically founded many years prior to the event. Even curious schoolchildren knew what to do in order to fly in space. Another matter indeed was that few had any idea of how to do it. The progress of Soviet science on the whole, innovative work in the field of rocket engine design, means of automation and control, high-speed aerodynamics and, finally, rocket design itself and the overall high level of technology made it possible to open the space age on October 4, 1957.

Manned flight in space has increased many times the number of engineering problems. I shall name only two problems, each of whose solution required the efforts of many research groups. The first was the creation of a reliable life-support system that could guarantee an active life for an astronaut during all portions of the flight. The second was to develop a descent in dense atmospheric layers at velocities greatly exceeding the speed of sound. The history of the solution of these two problems alone is a very interesting scientific epic.

But the flight of Yuriy Gagarin could in no way be considered a purely engineering problem. After all, a very simple and yet a very difficult question had to be answered before sending a man into space: isn't space

*Numbers in the margin indicate pagination in the foreign text.

harmful to man's physical nature? Food, water, fresh air, heat, normal barometric pressure--everything of which our physiological well-being on Earth is made up is provided precisely by technology. But this most important question was no longer one for engineers. Physicians, physiologists, specialists in aviation medicine, all those who had created the young branch of that most ancient tree--space medicine--had to answer this question. And they answered: space is not harmful. They had faith in their hypotheses and experiments. They answered for mankind. They asked only that man be stronger--one could understand them. /213

I do not want in any way to belittle all the success of engineering space thought. It is clear to everyone that, let us say, the "Vostok," "Soyuz," and "Salyut" are not simply different spacecraft, but rather spacecraft of different machine generations. The fact that the orbital stations of the future and manned interplanetary spacecraft will require of their creators even bolder, more intelligent and refined technical solutions is evident. Not so long ago during a meeting with students at the Moscow Physics and Technical Institute, cosmonaut Nikolay Rukavishnikov, answering a question on the complexities of a hypothetical Martian expedition, exclaimed: "Show me the design engineer who will give a guarantee that his instrument won't break down a single time during three years of constant operation!"

Of course, all the difficulties are not exhausted only by the requirements of reliability. Their number is great. Why do certain specialists in the field of rocketry nevertheless believe that maintaining man's further penetration into space will not be complexities of engineering problems? Their arguments are quite convincing.

In principle they say that today there are no unsolvable engineering problems that would hinder flight to Mars, for example. Draft projects of a similar nature exist, and there is nothing fantastic, or fundamentally impossible in them. Manned flight to Mars from an engineer's point of view is today a quantitative problem rather than a qualitative one, which it was for F.Tsander, let us say.

More complex than the engineering problems is the socioeconomic factor. The tension in political life, the arms race, and obstacles in the path of peaceful scientific cooperation have hindered and certainly do and will hinder the progress of astronautics. Meanwhile, future manned flight to other planets is now being pictured more and more frequently not as the point of any single national space program, but rather as the result of scientific cooperation between different countries. The impassive calculations of economists prove this. Whereas the most costly technical undertaking in all the history of man--the Apollo program--was estimated at 25 billion dollars, then manned flight to Mars is roughly estimated at 100 billion dollars. It is today difficult to conceive of a nation that could afford such expenses even for the sake of the glory of becoming the homeland of the pioneers of Mars. In 1973 in Pasadena at the Jet Propulsion Laboratory of the California Institute of Technology, American engineers in talks with Soviet scientific journalists said: "Well, of course we'll fly to Mars together. We can't strive all by ourselves, the undertaking will be too costly. . . ."

I think there is no sense in pausing longer on the socioeconomic factors influencing the further progress of manned space flight. Everything there is clear or, to be more precise, there are no debatable issues with you: the policy of peace and detente is an indispensable condition for international cooperation in space.

Now I would like to name the main factor capable in our current understanding (this stipulation is obligatory) of retarding the process of man's penetration into space. I am speaking of the one unsolved problem of space medicine or, to be more precise, the regretful limitation of that field in which certain laws developed by it, conclusions and recommendations have indisputable force.

In the numbered years of its existence space medicine has achieved extraordinary success. However, as frequently occurs in the struggles of any young science with the unknown, two new heads have arisen in place of each one that has been cut off. One such head was cut off long ago, but the neck proved devilishly muscular--this is the problem of weightlessness.

My task does not include even a rapid review of the works devoted /214
to a revelation of the secrets of the complex effect of weightlessness on human activity. I refer those interested to the outstanding popular publications of the correspondent member of the USSR Academy of Sciences, O. Gazenko, and other specialists. Yes, a great many such specialists are already known. Nevertheless, not a single specialist will take upon himself the risk of stating: "Once man lives for two or three months in weightlessness, this means he can live for a year, nothing will happen to him." Will or will not something happen? What can happen and when? How can unpleasantness be avoided? These are the main questions around which discussion revolves at all congresses, conferences and symposiums where specialists on space medicine meet.

Of course, the flights of the "Salyut" and "Skylab" have pushed the temporary boundaries of existence in space to two or three months, but they did not solve the mysteries of weightlessness. The most careful specialists warn of possible and difficult to predict changes at the cell level that can arise in tissue under the effect of long weightlessness.

Optimists, on the other hand, set their hopes on the unusual flexibility of the human organism and its amazing adaptability to the most improbable conditions. They hope that a scientifically founded method of physical exercise and further success in medicine will substantially increase the permissible period of stay in weightlessness. But even the optimists today will not write you a ticket to space either for three years or for one year, nor even for half a year. Their scientific conscience will not permit them to do this: they assume, but they don't know.

Lieutenant General of Aviation, twice Hero of the Soviet Union, pilot and cosmonaut of the USSR V. Shatalov in one of his recent articles acknowledges: "The question regarding the maximum period that man can stay under conditions of weightlessness remains very important for astronautics. One must obviously agree with the fact that such periods nevertheless exist. It is difficult to count on the fact that man, having left the Earth, could remain in space for an indeterminate time. But we do not as yet know these periods."

We are probably faced with the case when discussions on Earth cannot help. It would appear that the say rests with "his majesty's Experiment." And obviously that experiment or, to be more precise, a series of such experiments, must stand in a line of the most urgent scientific matters. Because, not having guessed the mysteries of weightlessness, we cannot begin to solve purely engineering problems in the future. Do you recall the old anecdote about how the animals decided what type of bridge to build across the river? The ass said, "First of all we have to decide how we'll build it: along or across the river?" So until we learn how long man can remain in weightlessness without impairing his health, we will not be able to decide how to build the bridge to the banks of outer space: along or across?

Imagine for a moment that as a result of research space doctors have established the following: despite all possible contrivances, they cannot expand the period that man can remain in weightlessness by more than up to one year. This immediately determines the maximum period that crew shifts can remain on orbital stations. It is precisely this time that must be taken into account when determining the operational resources of their scientific equipment. As far as the problem of long flights in space, interplanetary flights, are concerned, this period essentially dictates everything to the engineers. It is clear that in order to perform the program counted on for one year, a spacecraft does not need devices creating artificial gravitation, but in a spacecraft designed, let us say, to deliver an expedition to Jupiter's satellites, such a device is necessary. Artificial gravity and the additional energy consumption associated with it inavoidably entail the complication and weighting down of all the structural elements. The last condition requires more powerful rocket engines, and above all else the creation of new rockets. New, more powerful rockets, meaning larger rockets, in turn result in the need to create new, even huger (and more expensive) launching complexes. To put it succinctly, the costs and expenditures required to create the systems themselves with artificial gravitation amount to only a small percentage of the total conceivable costs and expenditures caused by the necessity to solve this problem. Naturally, this huge amount of work is capable of slowing down the rate of development of astronautics.

Thus, in general, only one particular problem of space medicine is strongly linked with the huge number of purely engineering problems. As you see, the wise serpent--the emblem of physicians--is today not only bent over the staff, but its ends are also closely entwined around the engineer's calipers. /215

LIFE ON THE CEILING

Despite the fact that Valeriy Bykovskiy flew on a spaceship for almost five days and it was accurately written in the press that he "lived in space," the "Vostok" was nevertheless a craft for flying and not for living. In a passenger plane you and I eat, drink and sleep, but we are still flying and not living there. On the "Soyuz-9" A. Nikolayev and V. Sevast'-

yanov did live: the two spacecraft compartments created a certain illusion of an apartment. And the Salyut orbital station is simply a space house. This progress in space technology has most often been noted in purely quantitative terms--data are compared on weight and volume, but it was forgotten that extremely important qualitative changes were after all being made: in ten years Soviet space technology, refining itself in different areas, has converted a transportation vehicle into housing. Centuries would be required for a similar conversion in shipbuilding, let us say.

The law of the development of science and technology is one from the simple to the complex. It is precisely in this manner that we have obtained the modern electric light, the automobile, and the nuclear particle accelerator. In this sense the Vostok was a unique creation: no one, nowhere, at no time had built spacecraft. The draft sketches of Kibalchich, Tsiolkovskiy and Tsander had no practical value for designers. This was that most rare of cases in science and technology, when the designers began from scratch. But when the absolutely innovative general problem, guided purely by engineering psychology, was developed into particular problems, the designers began to look around: what was there more or less similar that was already in existence? Gagarin's seat was therefore designed on the basis of aircraft ejection seats, the ancestor of his pressure suit was that of high-altitude pilots, the control panel was also somewhat reminiscent of the instrument arrangement in airplanes, etc.

I am saying all this not to reproach the space designers by any matter of means. It is simply that aviation--the branch of technology most like astronautics--was obligated to share its achievements with the latter. If the space designers had not made creative use of aviation experience, they would have acted most unwisely and the process of the creation of space technology would have lasted for many more years. I also note that professional pilots were the first to be trained for space flights, so any "aviation" design decisions to which they were accustomed were desirable even from the purely psychological point of view.

Candidate of technical sciences S. Darskiy in his work Ergonomika na kosmicheskom korable* observed that "an attempt was made when designing the Vostok to build the cabin in accordance with recommendations of engineering psychology (or, as they now say, ergonomically rational). A unified data and control system was created for the first time in the history of aircraft construction. Multi-functional instruments facilitating the work of the cosmonaut appeared." This is the solemn truth, but not all these devices appeared primarily because they were the last word in science and technology or were the highest scientific achievements or because they took into account the conditions of space flight. Unified data systems and multi-functional instruments subsequently appeared on many purely terrestrial objects.

Technology became more complicated, space crews increased, scientific research programs expanded, and the number of keys and indicators on the control panels grew, but again these were quantitative changes. The philosophy of designs remained as before, whether the spacecraft was one "for flying"--the Vostok--or one "for living"--the Salyut. All these seats, control panels, cabinets and panels on the inside were made from Earth designs and likenesses. I make a special reservation: I am speaking not

*Ergonomics on Spacecraft.

about systems specifically for space technology such as orientation systems, for example, in which it is more difficult to find terrestrial designs and likenesses. I am speaking only of the physical world surrounding the cosmonaut in flight. The unique behavior of objects and especially of liquids in weightlessness, of course, also required engineering contrivances and design wit and imparted (to the joy of journalists) a certain zest to space existence: food in tubes, a vacuum electric razor, original sewage disposal devices, etc. But if one excludes these purely specific details, the space world surrounding man is outwardly very reminiscent of the terrestrial world. After photographing the control panel in a landed Soyuz spacecraft you would easily convince even a technically competent person that before his eyes is the cabin of a new air liner, and a photograph of the Salyut compartments can easily be taken as the picture of, let us say, a submarine research laboratory. A characteristic detail: in the detailed work of S. Darskiy on spacecraft ergonomics, to which I have already referred, the word "weightlessness" or its synonym is not mentioned even once. /216

It is curious that we observe the very same picture in the history of the development of American astronautics. In the US there are the same aviation roots, the similarity of terrestrial interiors, and the same transfer of customary terrestrial surroundings to space. I am far from thinking of any sort of borrowing. I can speak only about the closeness of the logic in the scientific search--both we and the Americans began from the beginning.

Weightlessness immediately announced itself. Yuriy Gagarin recalled how his pencil "floated away" somewhere. From his first, eighteen-day flight Vitaliy Sevast'yanov brought home as a souvenir some woolen socks with holes in the little toes: it was precisely with his little toes that he pushed away when he "swam" in the Soyuz-9. Andriyan Nikolayev frequently rested on the "ceiling": there was more room there.

Astronauts intuitively sought the most convenient and natural interrelationships with weightlessness. Astronaut Charles Conrad took part in the design of the Apollo lunar cabin. The limited size of this cabin hindered the installation next to the control panel of a seat or even a stool. The designers stubbornly sought a solution. With great difficulty Conrad managed to convince them to throw away this piece of "furniture" and to limit themselves to leg restraints. Having already twice flown into space prior to this flight, he knew that it is no easier to stand in front of the control panel than to sit in weightlessness. A bicycle ergonometer was mounted on the "ceiling" of the Salyut-4 Soviet orbital station, which did not hinder a single one of the cosmonauts from exercising while another worked on the "floor."

Weightlessness has constantly seemingly tried to demonstrate to us new possibilities that it presented. And we, having obeyed for centuries the conservatism developed for us by the Earth's gravity, were timid and did not dare to make use of gravity's gifts. But did the matter lie only in timidity and oblivion to all the paradoxes of the world of weightlessness? Of course not. Each system, apparatus or instrument was created with an obligatory consideration of the specific working conditions in space, and primarily with a consideration of weightlessness. But at first it was difficult to purely speculatively imagine how it would be better and more convenient for man to live and work in space. Moreover, flight preparations sometimes lasted many months and during training under Earth conditions the astronauts had to work out all their own program designed for space conditions.

Designers understood that what is good for space may not be suitable for Earth, and vice versa. Let us say that the solar battery panels open up by means of a simple spring mechanism under conditions of weightlessness. But if this mechanism is tested on Earth, it may not eject the panel, since on Earth the panels do have weight and in space do not. The force of the spring does not change in space. But let us assume that a powerful spring can be made for the sake of insurance, which will also eject the panels on the Earth. But then the wings of the battery will be damaged under the effect of their own weight. For the tests the bellows panels were placed vertically like a screen, casters were fitted to the bottom, and when the spring mechanism was tripped the panels rolled on these casters along a smooth floor.

In contrast to spacecraft, orbital stations, just as solar batteries, are designed to operate only under conditions of weightlessness. However, they were also constructed according to terrestrial standards. I was able to spend some time in the models of the Salyut and Skylab orbital stations. The inside of the Salyut actually is reminiscent of a submarine: there are /217 compartments, a passageway in the middle, a floor and ceiling, equipment and units along the sides. The space of Skylab is somewhat differently organized, but it also has quite distinct floors and ceilings, and the concepts "top," "bottom" and "side" exist specifically and precisely. If the naval analogies are continued, then Skylab is more similar to the engine room of a large steamship. It is also divided into compartments, but these are joined by vertical ladders. To put it briefly, you will feel normal on the Earth in the Salyut if it is lying down and in Skylab if it is standing.

Why is this so? I assume that this arrangement only reflects the long-standing traditions of the space industry in the two countries. It is well known that in the Soviet Union orbital stations are assembled in the horizontal position. In this position the cosmonauts went through all their training. Assembly of the rocket-carrier, the joining of the spacecraft to it, the ground tests and transportation of the entire rocket to the launching pad are also carried out in the horizontal position: the rocket lies. The Americans perform the same operations in the vertical position: the rocket stands. Thus, the arrangement inside the orbital station is based on the principle of what is "most convenient and customary." Most convenient and customary for the designer, and simultaneously most convenient and customary for the astronaut. Design engineers have quite consciously tried to create terrestrial interiors in space and to free the nervous system of the astronaut from the need for additional psychological adaptation. So many different previously unforeseen experiences were heaped on the astronaut in space as it was that it was of course not worthwhile to intensify the astronaut's uncustomary, although perhaps more rational and convenient, situation under the new conditions. The designers understood that in space their orbital stations do not "lie" and do not "stand"; they understood that under conditions of weightlessness floors and ceilings are abstract concepts. They understood, but they closed their eyes to this and continued to draw ladders that were already senseless because they had lost their function.

Only very recently has weightlessness begun to be considered when placing various systems inside orbital stations and an interior layout permitted that is not the most advantageous for conditions on Earth. I discussed this with the commander of the new space expedition, Boris Volynov, prior to the flight of the Soyuz-21 and the Salyut-5:

"I think that the placement of approximately one-third of the instruments and equipment of the Salyut-5 implies that it will be more convenient to use this equipment in space than on Earth," said the cosmonaut. "Weightlessness is capable of saving living space. For example, a vacuum tank designed for the best adaptation of the organism to flight conditions is located on a 'wall' and it is most convenient to climb into it by moving along this 'wall.' On Earth it would have to be mounted on the floor, because even if someone were to help me and I climbed into this space on the wall, it would tear away under the weight of my body."

And so we come to the time for recognizing weightlessness as one of the deciding factors in space design. Whereas the initial stage in the mastery of space is characterized by a conscious departure from the possibilities which weightlessness presents to man--and this has its own logic--now it is possible to guess in the future an organization of space that will not have any terrestrial analogies at all. But what is the organization of space in principle? It is architecture.

A 'DOUGHNUT' GOES INTO ORBIT

Strictly speaking, there should be a question mark in the title of this article, since the question as to whether or not the architecture of weightlessness exists remains open. Architects simply do not know at this time whether they will be admitted to that very enchanting world where apples do not fall. The architecture of weightlessness will arise and will be in a condition to develop only under the indispensable condition that man be able to ive without limitations in weightlessness. If the engineers are compelled to create artificial gravity for man, we can speak only of certain modifications of architecture and design that will differ to a smaller degree from terrestrial variants the closer the engineers are able to approach the Earth's gravitation.

From the time of the "ethereal settlements" proposed by K.E. Tsiolkovskiy, no small number of projects have been put forward for similar structures, most often projects of a fantastic nature. The "air city" of the sculptor Pierre Sequelles, which was to orbit the Earth in one day, is one example. In this city, according to the author's belief, there would be a universe control center. The sculptor Koshitse designed a "suspended city" soaring above the Earth. The authors of similar "bold" projects usually did not trouble themselves with even approximate energy calculations, leaving the engineers to solve why all these fantasies should fly and not fall. /218

Among the projects of "ethereal settlements," however, there are technically based and even mathematically described projects in the first approximation. The most widespread variant was probably a toroidal construction, simply speaking a "doughnut" and a plan with widely spaced masses rotating around the overall center of the masses, similar to barbells. There are other variants of "doughnuts" and "barbells"--every possible type of wheel with spokes and axes.

In 1973 at Princeton, American scientists told Soviet scientific journalists about the "great Princeton doughnut." They spoke of an installation for generation of hot plasma--the prototype of a thermonuclear reactor--of the Soviet "tokamak" type. And the idea of another "doughnut" has recently arisen, a thousand times greater than the thermonuclear one. The so-called Princeton group of O'Neil--physicists, power engineers, designers--developed a project for a permanent toroidal orbital station rotating around the Earth in lunar orbit. One and one-half kilometers in diameter and costing 100 billion dollars according to the calculations of the "Princeton group," the "doughnut" can take on board about ten thousand persons. In addition to scientific research, these people will be engaged in various branches of production, based on the use of space conditions (deep vacuum, weightlessness, temperature drop) and, most importantly, will accumulate, convert and in the form of radiation transport solar energy to Earth. Scientists believe that the rotation of the "doughnut" will create artificial gravity on board the station, close to the Earth's gravity.

Another project on an extraterrestrial settlement about 400,000 kilometers from the Earth and Moon and designed for 10,000 persons was published in 1975. This "ethereal city" is a cylinder with a diameter of 100 meters and 1 kilometer long. Rotation around the longitudinal axis at a rate of one revolution every 21 seconds will create an artificial gravity close to the Earth's. The author of the project, P. Parker, believes that 98 percent of the materials needed for this space construction can be found on the Moon, for which purpose a colony will have to be created there with a population of approximately 2000 persons. After construction is completed, these people will become the first inhabitants of the "ethereal settlement."

I would like to note that, in addition to rather substantial energy consumption required by artificial gravitation, there is another negative quality. In the work Kosmonavt v sisteme kosmicheskoy navigatsii*, cosmonaut Ye. Khrunov and candidate of technical sciences N. Romanteyev emphasize that "the operation and use of various astronavigational aids in flight require of the crew knowledge of the heavens and steady habits in carrying out orientation and navigation processes using the spacecraft control system." Rotation of the "doughnut" will inavoidably hinder the execution of similar scientific observations sometimes made with great precision. Tales of expedition members on the Soyuz-4 orbital station confirm that well-coordinated and clever crew work is required for such observations, not to mention the fact that nature sometimes severely restricts their duration. Studies of the huge solar flare of June 15, 1973, by astronaut Paul Weitz during his flight on the Skylab lasted only three minutes, of which one minute went to directing the instruments to the site of the flare. I can't even imagine what sort of tracking systems or other technical contrivances will be required for similar observations on a

*The Astronaut in the Space Navigation System.

rotating "doughnut" and I very much doubt that such observations can be carried out at all.

Thus, structures with the generation of artificial grav- /219
ity are certain transitional variants from terrestrial conditions to weightlessness, variants of a "lightened world" in which life in its external manifestations will more or less correspond to terrestrial existence. With a little skill, after training a person will be able to learn how to walk and lie down and to hold all movable objects surrounding him in relative obedience. The Apollo expeditions, for example, showed that in a lunar world six times lighter than on the Earth, approximately twenty minutes are needed to learn how to walk and to acquire a special "lunar" bearing, which physicians called the "pose of an old ape."

Everything that has been said about the "light world" of spacecraft with artificial gravitation is to a certain degree valid for the Moon and for all possible types of settlements on Mars or the satellites of Jupiter. I am certain that the monstrous natural conditions of Venus and Mercury will still not overpower the all-conquering human curiosity, and expeditions of earthmen will land on the surface of these planets as well. However, the construction of stationary settlements on them will scarcely become a matter for the nearest foreseeable future.

All these heavenly bodies have masses less than that of the Earth and in this sense are "light" worlds. Again, there exist no small number [illegible] more or less technically based projects for settlements with a con[illegible] tion of the natural conditions of similar bodies. Most of these p[illegible]s are for the Moon. The well-known innovative architect Paul Maymon[illegible]ing worked for a long time on the problems of building on the ocean fl[illegible], has published the plan of a lunar city externally reminiscent of an open fan. A body of metal pipes and prestressed cables holds a roof of steel and plastic fabric. The problem of the foundation, which consists of sacks of steel fabric filled with lunar soil, has been solved in a curious way. The architect and sculptor Kenneth Snelson created a plan for a settlement on another planet with a frame made of pipes and cables imparting to the entire construction maximum strength and resilience. The "metal" spheres of Snelson would obviously not be suitable for martian settlers, who can expect hurricanes and dust storms. Soviet scientists have proposed that formations and craters already formed by nature be used for construction. Covered by a roof and interconnected by underground walkways, the latter can also form a vast extraterrestrial settlement. A plan for an independent lunar colony developed by the Americans John Dossy and Guillermo Trotti was published in 1975. This colony, designed for 200 persons, should be located near St. George,* not far from the landing site of the Apollo-15. It is a structure, half-covered by the lunar soil, with three complexes for the launch and landing of spacecraft. The colony will include hangers and repair shops for space equipment, scientific research laboratories, electric power stations, farms for raising plants and cattle, a factory for producing various products, housing and administrative facilities and a recreational center. This plan was developed with a consideration of the modern potential of rocket and space technology and can be carried out within the next ten years.

*the crater

This and many other plans are quite interesting and original, but they are all strongly based on terrestrial architecture. Cities under domes and closed settlements with artificial climate have also been designed for our needs on Earth, for polar regions, for example. Spheres similar to those of Snelson were designed by his teacher Bachminster Fuller and have become very widespread on "Earth" (for example, the central building of the exhibition complex at Sokolniki Park in Moscow). Of course, it is very difficult to build on remote heavenly bodies, one hundred times harder than in Antarctica, but nevertheless we more or less imagine what and how we will build in those areas. We already know, at least from the example of the Moon, that a "light world" is a quite specific environment, that the nature of the new worlds of "reluctance and "laziness" will be subordinated to our terrestrial rules. We understand how much effort and ingenuity is required of architects for this fascinating work outside the Earth. In this regard we must applaud the initiative of the pro-rector of the Moscow Architectural Institute for scientific work, S. Ozhegov, who thought of creating a special department where problems of the "architecture of extreme conditions" would be worked out--isolated structures of polar regions, underground complexes, settlements on other planets. /220

But a "light world" is for us earthmen only a transitional environment from the world of gravity to the world of weightlessness. This is a fundamental and qualitative transition. It is well-known that the laws of aerodynamics change beyond the threshhold of the speed of sound. Even more profound changes await us there. But before coming to this new threshhold we must make a stipulation. It is sufficient to remove one keystone from an arch for the whole dome to collapse into ruins. It is sufficient to remove from my speculative structures only one assumption, and precisely the assumption that man can live for a long period under conditions of weightlessness, for all these arguments to immediately become verbal trash. Modern triumphs of science and the eternal all-conquering inquisitiveness of the human mind permit us to hope that in the future weightlessness will not be able to dictate to man the periods of his stay in space. And then and only then will another problem of a truly universal scale stand before man. The problem is already not speculative under whose conditions there will be no saving phrases "let us assume" and "let us suppose"; the problem is specific and vital: to create a fundamentally new architecture not at all similar to the architecture of weightlessness.

THE GREAT FREEDOM OF WEIGHTLESSNESS

Imagine for a minute that people from nature could fly like swallows or bees. How much would this one condition change the entire appearance of terrestrial architecture! Where would we live? In nests? In beehives? The broadest field for fantasy is opened here. The fact that architecture would be delivered from the most ancient element existing throughout time, for all peoples, in all buildings from the Parthenon to a peasant hut, namely, the staircase, this one thing in itself is already a revolution.

But even winged people would live in a world of gravity and their architecture would continue to be subordinated to the laws of this world. These laws would determine not only the entire technology of construction, but also the esthetics of architecture, our ideas of what is correct, beautiful, harmonious, etc. "Architecture rests on constant principles, on the eternal laws of equilibrium, proportionality and harmony," writes the outstanding architect and public activist, winner of the Lenin Peace Prize Oskar Niemeier (author's underlining). It is precisely the permanent weight and eternal laws of Newton's apple that determine the face of terrestrial architecture, turning it into the architecture of organized surfaces. The floor and ceiling are the result of the force of the Earth's gravitational attraction, and so they are eternal. But what intricate projects have been executed recently! Jack Couelle, for example, defending in practice his idea of using structures of living organisms in architecture, built curved houses reminiscent of amoeba and infusoria. But the floor in these fantastic houses is ordinary, because even the most refined snob doesn't want to live in a room with a curved floor. It is validly noted in a foreign article on design that "feet themselves feel that under them are tiles or a rug, and they are especially sensitive to an inclined floor." "The vertical in architecture helps man keep his body straight. Inclinations are dynamic because they signal equilibrium to the human senses," writes the English architect Mitchell Leonard in his curious work The humanization of space. Without touching on the problems of weightlessness, he remarks casually that it is precisely gravitation that forces us to prefer horizontal surfaces because motion along sloped surfaces requires a certain effort to keep the body in its customary position. "As a hypothesis," writes Leonard, "I want to propose the assertion that there is a relationship between the shape of the surrounding space and the magnitude of the reaction to this shape of the muscular tension of the organism." But after all this muscular tension is the direct consequence of the force of gravity. And this means that any architectural shape will also be in direct relationship to it.

In fact, all buildings on Earth for all time, whether they be the cave cities of ancient China or the skyscrapers of New York, have always been divided by something horizontal--call it a story, a floor, a ceiling, a gallery, a balcony, as you wish. The connection of these horizontal elements is the essence of architecture. In principle, Corinthian columns /221
and walls of glass and aluminum do the same thing: connecting the horizontals, they create volumes. But it only seems to us that we populate these volumes. In actually fact we populate the surfaces. It is not after all without reason that we measure our housing in terms of square, and not cubic, meters.[1]

I will take the risk of proposing the following formulation: a plane perpendicular to the vector of the gravitational field is the basic element of any architecture existing in any gravitational field. Therefore, apologizing beforehand to architects, I permit myself to call terrestrial architecture plane architecture. This seems to me permissible as compared with the truly volumetric architecture of weightlessness. But what is this architecture, you ask. Unfortunately, there are few people who have thought about this and so it is rather difficult to answer such a question. Proposals of the "practical workers of space" are quite timid. Here is how cosmonaut N. Rukavishnikov and candidate of technical sciences G.

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[1] I want to be correctly understood: cubic meters are very necessary for light, air and health, but we do live nevertheless on square meters.

Morozov describe this "ethereal settlement" in their joint work The cosmonaut scientist (Kosmonavt-issledovatel'):

"The external appearance of an orbital station differs from that of modern ships. On the former there will be several isolated facilities, each of which will be a unique, independent laboratory: medical-biological, astronomical, technological, meteorological, etc. In these laboratories the cosmonaut scientists will conduct their planned experiments either personally or using automatic scientific equipment which they must service. A special housing unit with sleeping areas, cabins and domestic facilities is proposed for the station for purposes of relaxation, sleeping, eating and executing hygienic and physical exercise procedures. This unit will be a unique hotel for the crew and for the scientists on board the station. Certain laboratories may be made in the form of separate independent modular designs that can depart from the main base station, go into another trajectory and return to the base after completing a certain cycle of tasks."

This is marvelous! But the most interesting thing is to learn what sort of laboratories, cabins and sleeping areas will these be. How will the scientific space center differ from those on Earth--only in the capacity of individual laboratories to detach themselves from the main building? After all, a large underwater laboratory can be made on Earth, from which research submarines and bathyscaphes can depart. And when we step from the airport building directly into an airplane through a mobile corrugated corridor we are also "detaching ourselves" and then going into a new orbit.

Specialists in the field of astronautics are speaking more and more frequently not only of man's stay in space and not even only about his scientific research there, but about his active work outside the Earth, presuming the creation of material values for all of society. Academician V. Glushko writes that "it is being conceived in the more remote future to gradually put into space industrial and even energy production in order to preserve our planet from the destructive influence of technical progress."

Our brief experience in space work already shows that any work in the world of weightlessness acquires substantial distinctive features. On Earth we seemingly do not waste our efforts on holding our bodies in the vertical position. We don't think about this, just as we don't think about our need to breathe. Instinct and experience in terrestrial life have developed in us certain, purely terrestrial habits in our contact with inanimate nature and with the tools of labor. Neither the ape nor man will even try to lift a box by grabbing it on the corner. If you must turn a heavy wheel, you will quite unconsciously take it by the rim and not by the hub, without thinking of the laws of mechanics, and possibly without even knowing them. If you have to move a pole or a log, you will, also without thinking, try to hold it near its center of gravity.

In a world where a log can be moved by taking hold of its very end, all these instincts are useless, and experience is even harmful. Other instincts must be developed and different experience must be acquired there. And it is doubtful that anyone today has the courage to predict how a science laboratory or a factory shop will look in the world of con- /222 stant weightlessness or that anyone has the imagination to draw a picture of the production process in this shop.

One of the creators of modern architecture, its greatest theoretician and outstanding practitioner Gropius, once wrote bitterly: "We were always deficient in science, but today it is pushing us out of our state of equilibrium ... and in its hurried advance overshadows other components needed to harmonize human life. Of course you would not call this the age of art, would you? This is the age of science."

Gropius lived a great life. When he was a child, aviation and cinematography were born, when he became a young man the atomic nucleus was split, and when he became an old man, men flew into space. He died only two weeks before the first lunar expedition of earthmen. He saw the greatest triumphs of science and technology and the bitterness of his words is understandable, and the reproach is probably just. But how could this great architect not understand that it is precisely on the foundation of this tremendous scientific progress that a building of an unforeseen architecture may be built? After all, it is precisely to him that the remarkable sentence that "the historical mission of the architect always lay in the achievement of total coordination of all efforts aimed at creating man's physical environment" belongs.

And now before us is a qualitatively new physical environment--weightlessness. What efforts will it require of the architect? It is very difficult to answer this question. At the present time there are no recommendations or rules for building houses in weightlessness. It remains only to be guided by the beautiful poem of Bulat Okudzhava:

> You build it like you write poetry,
> Like on a canvas, drawing
> Along the sketches of your soul,
> With all your heart, risking.

If anything, there will be more than enough risk in this construction. When I spoke about work on the Vostok, I explained why it was not easy to build such a spacecraft: it was the first and had no analogies. Construction in weightlessness will also have no analogies and it will be possible to speak only of its certain vague contours.

Any medium of habitation, including the space environment, on one hand determines and on the other hand requires modifications in the properties of the building materials that are used. Various alloys of light metals have until now been the chief building material in space. I am certain that in the future the palette of space builders will be substantially more variegated. We often speak of various "interdictions" imposed by the nature of space on engineering and design thinking. But it is wrong to think that space will always only "interdict." No, it will also "permit" builders to do much of what Earth "forbids." In this regard the innovative work of S. Shvartz is curious; in this work he examines the methods of preparing constructions that expand and harden in space. Saturated with special resins and compactly built, these constructions will expand and harden after being transported into space under the effect of the deep vacuum, ultraviolet and infrared radiation and the temperature drop. Thus, the nature itself of space, the "emptiness" of the interplanetary environment, the nothingness will become the allies of extraterrestrial architects. If one speaks of shapes, space presents us with truly unlimited possibilities. Let us begin with the fact that the architecture of weightlessness is the architecture of unlimited sizes. Tall buildings and television towers will set their own architectural records. New materials and the talent of design and construction workers will take part in this undeclared competition. But I don't think that anyone on Earth would build a house twenty-five kilometers high. In space it is possible.

The architecture of weightlessness is that of unlimited potential for shape formation. Neither the weight of buildings nor the quality of the soil under them limits you, and the bans on the inexorable strength of materials do not disturb you.[2] /223

Analyzing the plans of the aforementioned Paul Maymon, the leading French architect of our time Rene Sarger wrote: "Modern visionaries remain unintelligible only to those who can't imagine the truly fantastic potential of new technology." It is interesting that Sarger himself in 1962 founded the Scientific Research Institute of Technology and Architecture of Overstressed Shells. He created shell constructions in which only tensile forces emerged thanks to the double curvature. "These constructions actually produce the impression of sails filled with wind," wrote the architectural theoretician Michel Ragon, "and they seemingly become weightless." Architect Robichon confirmed, looking at the works of Sarger, that "we are witnesses of architecture expressing weightlessness."

In no way belittling the innovation of the French architect, who obviously has great prospects in terrestrial architecture, it should be noted that his success is very far from the actual potential of the architecture of weightlessness. No super-overstressed construction will allow you to build, let us say, a building in the form of an inverted "L" so that the top stroke would be ten (or one hundred!) times longer than the bottom stroke. But under conditions of weightlessness this is possible if only because there are no top and bottom strokes and height and length are identical concepts. Under conditions of weightlessness such concepts as "front" and "rear", in the case of the absence of spacecraft motion, will more correctly be replaced by the more definite "to the front" and "to the rear." And if there is no height and length, no front and rear, this means that something completely obligatory for terrestrial architecture becomes completely optional for the architecture of weightlessness. In terrestrial architecture it is possible to speak of diagonal movement in space (an example of this is the classic "St. Joseph's Home" by Frank Lloyd Wright), while in weightlessness this is impossible because it is meaningless. If there is no height, this means that there are no eternal floors and ceilings on Earth. For an inhabitant in weightlessness it makes no difference what type of floor is in his house--straight, sloping or

[2]More precisely, there will also be strength calculations in this case. Let us assume that the external vacuum and pressure inside the space house require respect for the strength of materials, but this will already be not that construction strength of materials which binds the architect by the hands and feet on Earth.

curved. The inhabitant will live not in an apartment, but rather in a volume. He will require from the architect an organization of space and not of an area; this organization will be such that, sitting on the ceiling, as on current orbital stations, he will not suspect that he is doing so. The parallepiped of the room under conditions of weightlessness will naturally and logically be reborn into a sphere--an ideal space of equal potential.

The sphere has always attracted terrestrial builders, while gravitation did not permit its use and limited its potential to hemispheres and domes. The attractiveness of the sphere is explained, on one hand, but its purely geometric nature: it is so capacious that its further division is impossible; on the other hand, this attractiveness is explained by the fact that it is a geometric shape with a maximum volume when the surface is minimum. In other words, by using the sphere (or hemisphere) you will spend a minimum amount of building material to create one unit of volume. In this case the economic benefits that are indisputable on Earth will be especially felt at the first stage of the emergence of "ethereal settlements," when the building materials will be supplied from the Earth or Moon and their weight will scarcely become their first characteristic.

Following the logic of weightlessness, we shall see that if a room is regenerated into a sphere, then a corridor is converted into a pipe, and a door becomes a hatch. And the door-hatches from the corridor-pipe will not be placed to the left or right, but rather over the entire circumference of this pipe.

Nevertheless, the socks of Vitaliy Sevast'yanov with holes in the toes involuntarily suggest the idea that the terms "sphere" and "pipe" are obviously not entirely accurate. It must be assumed that this is not exactly a sphere or a pipe. The complicatedness of the shapes will be dictated by the physical size and the kinematics of the human body. Under conditions of weightlessness, as on Earth, it is not possible, let us say, to take into consideration the fact that the human knee bends backward and not forward as for a grasshopper. Imagine that you are floating /224 in a certain pipe, pushing off from its walls to gain speed. It is clear that it would be more convenient to float if these walls were not smooth but rather corrugated. And by the term room-sphere I mean, to be more precise, a certain polyhedron, a certain complex closed volume whose inner geometry is built with a consideration of human convenience. We therefore leave the terms "sphere" and "pipe" only for the sake of simplicity, implying the conditionality of these concepts.

Thus, let's try to look at our new space settlement. In the room-sphere such a simple and ordinary thing as, for example, a table, becomes a complex, inconvenient, non-functional item, as the designers say. You would agree that if there is no floor or ceiling in the room that furniture can have no top or bottom. A table with pedestals or legs is logically regenerated into a cube and, it seems more probable to me, into an icosahedron--a polyhedron composed of equilateral triangles. This is not good. If this table can be fastened with some sort of hard compound or magnetic field, then this is already a question of technology. The main thing is that in weightlessness a person will be comfortable sitting at a table-icosahedron, no matter what side he sits on. Sits? Terrestrial terms already bother us. "A man sat in a chair"--in weightlessness this is a purely arbitrary concept, and this chair is not needed as an object devoid of any function. Even in the "lunar" cabin of the Apollo, as you recall, it was unnecessary.

In terrestrial life there are quite definite verbs "to lie" and "to sit," describing positions that are, so to speak, directly contradictory. But in space there is an equals sign between "I am lying down" and "I am standing up." I remember the Crimea in August 1961 when German Titov, who had just returned from his day-long space flight, was vacationing with Yuriy Gagarin. Titov said a lot about his "stellar days," but when I asked how he had slept, he began to think:

"I really don't know. Perhaps standing and perhaps lying down. Who knows? After all, there's no difference in weightlessness."

I recall that those words struck me most of all. It was necessary to perform some definite and quite uncustomary mental work to understand not just with my head but also with my heart that a vertically standing bed, absolutely impossible on Earth, would not look silly in a world where the vertical is equal to the horizontal. In our life on Earth any human endeavor is necessarily linked with a certain space attached to it. In order to chop wood, grind a part or write poetry, man's body must occupy a certain position or pose. This rule is also obviously valid for weightlessness. A surgeon will never be able to perform an operation by flying around the patient, or an astronomer to make observations while soaring around his telescope. On the Earth the body is primarily fastened by the Earth's gravity. Furniture in all its forms here only aids gravitation. Furniture is a function of gravitation. But under conditions of weightlessness fixed bodies are very arbitrarily linked with furniture. The first astronauts quickly understood that they could say "I am sitting in a chair" only when they were strapped in. The seat belt, and not the chair, bridle or horse, bears the main function.

Weightlessness requires a new "space" understanding of design. It opens truly unbounded prospects for the most daring search and the boldest experimentation. We are speaking here of the creation of a new structure, of that very extreme case which, in the words of N. Voronov and Ya. Shestopal, authors of the book Estetika tekhniki*, "arises when new principles, laws or discoveries that have not been formally or structurally realized come forward as objects of arrangements."

Incidentally, all the aforementioned does not at all threaten design by breaking its foundations (in contrast to architecture). And whereas one of the rules of "terrestrial" design, whose basis is arrangement, states that the effectiveness of the end result will be higher the more the initial objects are transformed, modified and adapted to one another and to the new general task, in the world of weightlessness this rule retains its full validity.

The motto of Le Corbusier that "the house is a machine for living in" always frightened me: a house is a house and a machine is a machine. And no matter what technical innovations are embodied in the architecture of /225

*The Esthetics of Design.

weightlessness, I want to believe that the inhabitants of "ethereal settlements" will still not live in machines. It is another matter that the conceptions to which we are accustomed concerning the house, comfort and beauty must necessarily undergo substantial changes.

It may be that the everyday concept of "my own home" will be converted in space into "my own little sphere." Those living in space will not know the charm of a spacious living room with beautiful heavy curtains, a round table, an orange lampshade or an old chandelier, a quietly whistling samovar and jam in grandmotherly rosettes. Thinking of this you experience a melancholy Chekhovian sadness, and you become sad for people floating in spheres around table-polyhedrons.

I imagine that one of the generations (and perhaps not only one) of space inhabitants in the remote future may be an unhappy generation, since time, tightly compressed by scientific progress, requires that the human heart forget the Earth until he loves space. But in the historical sense this will probably be a very short period. People in the "ethereal settlements" will become unaccustomed to our rectilinear rooms as easily as we became unaccustomed to caves, huts and izbas [peasant huts] without chimneys to their fireplaces. And if we speak frankly, having grown up with running water and electricity, we will rarely and not always sincerely long for wells and torches.

Today, when not even one hundred men have been in space, it is hard for us to imagine the future scale of the mastery and settlement of space. In the nearest future the flights of spacecraft that can be used many times will gradually reduce to nothing the heroic exclusiveness of the astronaut profession, and by the start of the 21st century we shall regard people working in space in the same way as we currently regard participants in Antarctic expeditions. The number of these people--astronaut-pilots, scientists, engineers, assembly and construction workers, power engineers, radio specialists, doctors--will grow from year to year at an ever accelerating rate in the manner of an avalanche. Calculations made by the famous Soviet astrophysicist, correspondent member of the USSR Academy of Sciences I. Shklovskiy, show that in five hundred years, and under the most unfavorable economic conditions in 2,500 years, about ten billion persons--considerably more than currently inhabit the Earth--will live in "ethereal settlements" within the Solar System. But even 2,500 years on the scale of history are not as much as they seem. A longer period separates us from Nefertite and Tutankhamen, and pharaoh Cheops, famed for his great pyramid, is almost twice as far removed from us on the scale of time as these future space inhabitants. Our remote, but on the whole close, descendents will be born in weightlessness and will live there permanently. And it is possible that very many of them will never fly to Earth and learn that in their great-grandfather's house there was a round table and an old chandelier. And if they do fly here won't it seem to them, born in unbounded spaces, that our houses are funny and ridiculous and that our rooms are strange and uncomfortable? And when they fly here, it will probably be very difficult and very unusual for them in the world of our gravity, in the world where man is so unfree that he can't even fly. Yet, who knows? Perhaps the future will place before physiologists and physicians a new problem, having turned our modern concerns from our feet to our heads: will a man born in weightlessness and having spend long years there be able to live on Earth? But if the success of modern science plants in us assurance that weightlessness will be conquered, then we have even more grounds for believing that the mighty science of the future will also manage with the reverse problem.

Recalling the fantastic books of my adolescence, I catch myself in thoughts that the underwater inhabitants of Conan Doyle's Chasm of Marakotovo or the aborigines of H.G. Wells' Country of the Blind produce a feeling of sadness in me, while I envied the invisible man and Ichthyander. Because in the first the authors took away something that we have, while the second group was awarded capabilities unaccessible to us.

I wish to repeat again: everything of which I have spoken is only a sketch, food for thought, nothing more. I am absolutely certain of only one thing: the future of astronautics, in addition to all its scientific and material benefits, is profoundly optimistic, for it is capable of giving man something very important: the previously unaccessible possibility of realizing the wildest dreams. When the forbidden becomes the /226
accessible, and the impossible becomes the possible, we are always afraid of this for a certain moment. Shall we not now experience this fleeting timidity, having stopped on the road of outer space and looking into the vague outlines of cities floating in the stellar abyss? We sense rather than know that beyond this threshhold the realization of the greatest of all our fantasies awaits us, and that the time is coming to combine all our knowledge and talents, the time for the most complete and the highest manifestation of human thought and the human spirit.

COMMENTS ON THE ARTICLE

by a cosmonaut:

Problems of space architecture arose as soon as man penetrated space. They undoubtedly exist today. It is true that the word "architecture" is not yet being used by specialists in the field of space technology. It is replaced by the words "shape," "arrangement," etc., but the essence from this is unchanged: proceeding from the new requirements and conditions, problems similar to those of architecture must be solved today.

For example, the problem of how to make an orbital station such that it holds all the necessary equipment and its mass remains minimal. How to give the station a shape that would permit its motion to be controlled in the easiest manner. How to create inside the station the maximum conveniences for the work and life of the crew under conditions of weightlessness. How to place the windows in order to provide the best view. Even the color of the outer surfaces must be specially selected when building spacecraft: this requires a specific coefficient of reflection guaranteeing the necessary heating conditions throughout the entire construction.

To put it briefly, there is already a large number of problems today similar to those being solved by "terrestrial" architects. The popular and fascinating work of Yaroslav Golovanov is therefore quite interesting to me.

Aleksey Yeliseyev, Doctor of Technical Sciences, twice Hero of the USSR by an architect:

Science and technology are developing so rapidly and they bring so many discoveries to mankind that the most impertinent fantasies are becoming realities. That is why the article of Yaroslav Golovanov, which the author characterized as sketches and food for thought, is undoubtedly of interest.

Architecture always surrounds man. The created life environment must also take into consideration the necessary conveniences for man under the most diverse conditions. However vague the future scale and prospects for mastering space, we should think beforehand of forecasting the environment of man's stay in space. The interesting and fascinatingly written article of Ya. Golovanov will help not only architects, but also people of other professions to give some thought to the most interesting problems of man's stay outside the Earth.

The examination and preparation of solutions to these problems require great ingenuity and inventions. After all, we are speaking of a fundamentally new architecture for conditions of weightlessness that differs from terrestrial architecture. The need for close cooperation between architects and specialists in space technology will inavoidably arise in the future. And one can only envy the young architects who will have occasion to carry out the first plans created for the world of weightlessness.

Georgiy Orlov, Professor, National Architect of the USSR